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ESTIMATION OF WARFIGHTER RESTING METABOLIC RATE

by
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14. ABSTRACT
The purpose of this study was to identify the best method for estimating the resting metabolic rate (RMR, kcal/h) of the warfighter, given the current level of available knowledge, using methods and data published in the literature. Several published equations for estimating the standard resting metabolic rate (RMRS), defined as the metabolic rate in the morning after an overnight fast, with the subject at rest in a thermoneutral environment in a supine position, were also evaluated. A series of comparison data sets of individual data from results published in the literature, in which obese subjects and subjects younger than 18 and older than 55 yrs, were eliminated. A comparison between estimated RMRS and RMRS values from the comparison data set showed that equations developed by Mifflin and coworkers in 1990 fit the data the best. It was determined that once inherent differences in the subject populations used to develop and test the equations were considered, that the equations developed by Schofield (1985) for the World Health Organization, provided the best fit to the data. From linear regression analyses on the

(Continued on reverse)

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ARMY PERSONNEL	METABOLISM	COMPUTATIONS	FOOD CONSUMPTION
WARFIGHTERS	ESTIMATES	DATA SETS	MILITARY RATIONS
RESTING METABOLIC RATE	FORMULAS(MATHEMATICS)	EQUATIONS	
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comparison data set, it was found that a combination of the estimated lean body mass (computed from weight, age and gender) and gender or the body weight (W, kg) with gender and age fit the data equally well [standard error of the estimate (SEE = 6.75 kcal/h)]. From a review of the literature, rough approximations to account for the thermic effects of food (TEF, kcal/h) and prior activity (PA, -1="sedentary", 0="moderate", +1="high") were developed. Assuming a linear-exponential relationship between TEF and time (t, min), i.e., TEF = at/b^t, a peak in TEF at 1 hour and a total area under the TEF vs. t curve over the first 6-hours after ingestion equivalent to 14% of the metabolizable food energy content (FEC, kcal), TEF at any time t after ingestion is given by:

$$TEF = (0.02376 \cdot t/1.0168^t) \cdot FEC/100$$

Assuming a difference of 6% of RMR due to differences in prior activity level, from sedentary to moderate or moderate to high, the adjustment (multiplying factor) for RMR to account for PA is: $(1 + 0.06 \cdot PA)$. Assuming the unadjusted equation developed by Schofield is appropriate for moderate prior activity, the final relationships for estimating RMR of the warfighter are as follows:

men: $RMR = (1 + 0.06 \cdot PA) \cdot (0.627 \cdot W + 24.22) + TEF$

women: $RMR = (1 + 0.06 \cdot PA) \cdot (0.617 \cdot W + 15.66) + TEF$

Results of this study need to be verified using a comparison data set representative of active duty military.

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Preface

Many of the mathematical models of human physiology of interest to the military require the rate of metabolic energy expenditure (metabolic rate) as a key input variable. These models include the Ration Evaluation and Analysis Program (REAP), the Ration Selection Program (RaSP), the US Army Research Institute of Environmental Medicine (USARIEM) "Scenario" heat stress model, and the Dynamic Nutrition Model (DYNUMO). These models currently estimate rates of energy expenditure for military tasks using statistical relationships and table lookup methods. Unfortunately, these relationships and tables are largely undocumented. It is the purpose of this report to review available data and methods for predicting resting rates of metabolic energy expenditure and to develop recommendations for estimating resting rates of metabolic energy expenditure for the active duty military population. It is intended that this be the first in a series of reports, with future reports addressing other activities (e.g., foot movement, lift and carry tasks) typical of military operations.

The work described in this report took place during the period May 2004 to September 2004 under Natick Contract Number DAAD16-02-C-0056.

This effort is supported by the DoD Combat Feeding Directorate at the Natick Soldier Systems Center. In addition to its general usefulness for models of human nutrition and thermal stress, this study was conducted specifically to obtain estimates of metabolic energy expenditure for project JSN 04-2, "Estimation of Optimal Ration Macronutrient Content for Warfighter Health and Performance," which supports JSN 99-16 "First Strike Ration" supported by the DoD Combat Feeding Research and Engineering Board (CFREB), sponsored by the Army, Marine Corps, Navy and the Defense Logistics Agency.

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In addition to support from the CFREB and the DoD Combat Feeding Directorate (Natick Soldier Center), the author would like to thank the Nutrition Division at the US Army Research Institute of Environmental Medicine, and the Modeling and Analysis Team at the Natick Soldier Center for the valuable guidance and resources they provided. I would also like to thank Sandra Fisher (Anteon Corporation) for her expertise and assistance in the final preparation of this document.

Executive Summary

Numerous formulas have been derived for estimating standard resting metabolic rate (RMR_S) from a person's age, gender, anthropometric characteristics and body composition. To evaluate the potential use of these equations for active duty military, we compiled a data set from the literature in which subjects who were obese (greater than 25% body fat for men, greater than 30% body fat for women) or who were over 55 years in age were eliminated. Although some athletes were included in this data set, the remaining were characterized as "healthy" in the original reports, but were likely more sedentary than average active duty military personnel. Only data in which body composition was measured were included. The total sample size was 86.

We first compared RMR_S estimated using various published equations with measured RMR_S from the comparison data set. Eliminating the Owen et al. (1986-1987) and Nelson et al. (1992) equations from consideration because some of the data used in developing the equations were also included in our comparison data set, the Mifflin et al. (1990) equations fit the data the best [standard error of the estimate (SEE=7.0, Δ=0.6±6.9)]. Equations for estimating the resting metabolic rate (RMR) of standing man ($RMR_{standing}$), which is used to describe RMR in the USARIEM heat stress and SCENARIO models, did poorly at estimating RMR_S from the comparison data set (SEE=28.5, Δ=26.0±11.0). The Harris and Benedict (1919) equations, used by the Combat Feeding Program's nutrition models (Ration Evaluation and Analysis Program (REAP), Ration Optimization Program Evaluator (ROPE), Ration Selection Program (RASP), Dynamic Nutrition Model (DYNUMO)) performed better (SEE =8.8, Δ=5.2±7.1), but were not as good as the Mifflin et al. equations.

There has been much discussion during the past 85 years as to whether resting metabolic rates measured as part of earlier studies (e.g., Harris and Benedict, 1919) are systematically higher than resting metabolic rates measured using contemporary methods on contemporary subjects. To eliminate any bias from the comparisons, each of the equations was adjusted by the average difference between estimated and measured RMR values (Δ). We then re-computed Standard Error of the Estimate (SEE) and other statistics. When that was done, the apparent differences in prediction power among the equations were greatly reduced. With the exception of the equation for $RMR_{standing}$, SEE's ranged from 6.6 to 7.2 kcal/h with a similar range of differences between predicted and measured values. Eliminating the adjusted Owen et al. (1986-1987) and Nelson et al. (1992) equations from consideration, the adjusted Schofield (1985) equation, did slightly better than the others (SEE=6.8, Δ=0.0 ±6.8, Δrange -22.7 to 17.3 in kcal/h). The adjusted Harris and Benedict equations did less well (SEE=8.8, Δ=0.0±7.1), while the adjusted equation for $RMR_{standing}$ continued to perform poorly (SEE=11.1, Δ=0.0±11.0).

To determine whether there was any advantage to using powers of body weight (W^b) or of using body composition over combinations of body weight (W), height (H), age (A), and gender (G), we also performed linear regression on the comparison data set. The variable with the highest correlation coefficient was an estimate of the lean body mass (LBMe), computed using A, G and W, followed closely by fat-free mass (FFM), body surface area (BSA), W raised to the 2/3 or 3/4 power, and W. The best fitting regression equations included LBMe and G, or W, G and A. There was a slight advantage of using W raised to a power of 2/3 or 3/4, which was

negated when G and A terms were added to the equation containing W. There was no advantage to using FFM and fat mass (FM) over W, G and A, because (1) there was no advantage to using powers of W or of using body composition over combinations of W, A, and G, (2) measurements of W, A and G are easier to obtain than FFM and FM, (3) W and G are used in the adjusted Schofield equation. We would recommend using W and G for estimating RMR for the warfighter.

The comparison data set used in this study is composed mainly of data from sedentary individuals. The primary difference between these subjects and active duty military are the daily activity and fitness levels, which would be expected to be higher in active duty military. Although it does not appear that fitness alone results in a difference in RMR once the effects on FFM have been accounted for, prior activity level does affect RMR. While there are insufficient data to develop a detailed, quantitative relationship between daily activity level and RMR, we were able to develop a rough adjustment to the Schofield Equations using differences in RMR among sedentary subjects in the comparison data set, subjects who were presumably more active on a daily basis due to lifestyle differences (Harris and Benedict, 1919) and elite athletes (Thompson and Manore, 1996). We would propose using the unadjusted Schofield Equations to represent moderately active individuals, including typical active-duty military personnel, and a decrease or increase in estimated RMR of 6% to represent sedentary and highly active (e.g., athletes in training, warfighters during high-tempo operations) subjects, respectively. The adjusted Schofield equations are provided below. In these equations, PA represents prior activity and is given a value of -1 for"sedentary" individuals, 0 for "moderately active" individuals, and +1 representing "highly active".

men: $RMRS = (1 + 0.06*PA)*(0.627*W + 24.22)$
women: $RMRS = (1 + 0.06*PA)*(0.617*W + 15.66)$

Although there are effects of circadian rhythm and environmental conditions (particularly cold exposure) on RMR, these adjustments are best handled within specialized models of sleep/wake and circadian rhythms and thermoregulation. The final factor affecting RMR considered here is the thermic effect of food (TEF). Although there were insufficient data to develop an accurate model of the effects, a rough approximation was derived assuming a linear-exponential function of TEF over time, a peak at 1 hour and a total area under the curve of 14% of the ingested, metabolizeable caloric content of the meal:

$$TEF = (0.02376 \cdot t/1.0168^{t}) \cdot FEC/100$$

where TEF is expressed in kcal/h, t is the time since meal ingestion in minutes, and FEC is the metabolizable food energy content in kcal. The total resting metabolic rate is the sum of RMR_S, adjusted for prior activity (PA), and TEF:

$$RMR = RMR_S + TEF$$

It should be kept in mind that estimations for TEF and effects of PA are very rough approximations. Future efforts should be directed toward obtaining appropriate RMR data from a population representative of active duty military and verifying these results.

ESTIMATION OF WARFIGHTER RESTING METABOLIC RATE

1. Introduction

In sedentary adults, the resting metabolic rate (RMR) accounts for 65-70% of the total daily energy expenditure (Owen et al., 1986). While the RMR may account for a smaller percentage of the daily energy expenditure in military personnel during high-tempo operations, the metabolic rate during resting activities is still significant. Furthermore, warfighter characteristics (e.g., weight, height, age, gender, prior activity, etc.), environment, and subjective time of day may all affect the rate of resting energy expenditure.

The standard resting metabolic rate is defined as the rate of energy expenditure upon awakening, following an overnight fast, in a comfortable environment without physical or cognitive activity or stress. In the past, this was referred to as the basal metabolic rate. However, the basal metabolic rate has subsequently been defined as the minimal, steady state metabolic rate compatible with life. The basal metabolic rate typically manifests itself during sleep in the early morning hours. Thus, we will refer to measurements made in the resting subject, in the morning, following an overnight fast as the RMR_S. The metabolic rate of subjects at rest, during other times of day, in other body positions (e.g., sitting), or at various times following the ingestion of a meal will be designated by RMR.

2. Methods

2.1. Literature Search

A literature search was conducted using the Medline and Defense Technical Information Center (DTIC) databases. The following search terms were used to generate Medline reports:

- "Basal Metabolism" (MH)
- (Metabolic or Metabolism or Energy) and (Basal or Rest)
- (Metabolic or Metabolism or Energy) and (Military or Soldier)

The DTIC database is considerably smaller and it was necessary to broaden the search terms. The terms *Metabolic*, *Metabolism*, and *Energy Expenditure* were applied separately. Relevant results are summarized in this report.

2.2. Notation

There are a variety of symbols and units used to describe anthropomorphic characteristics and metabolic rates in the literature. A common set of symbols and units will be used in this report, which are shown in Table 1 on the following page. Values taken from the literature are converted from their original units to those in Table 1.

Table 1. Symbols and Units

Symbol	*Description*	*Units*
W	Body Weight	kg
H	Body Height	cm
A	Age	yr
G	Gender (1=male, 2=female)	na
PF	Percent body fat	%
FFM	Fat-Free Mass	kg
LBMe	Estimated Lean Body Mass	kg
FM	Fat Mass	kg
BSA	Body Surface Area by the Dubois & Dubois Formula	m^2
BMI	Body Mass Index	kg/m^2
VO_{2max}	Maximum Rate of Oxygen Uptake	l/min
RMR	Resting Metabolic Rate	kcal/h
RMR_S	Standard Resting Metabolic Rate	kcal/h
TEF	Thermic Effect of Food	kcal/h
PA	Prior Activity (-1 = sedentary, 0 = moderate, +1 = high)	na
FEC	Food Energy Content (metabolizable)	kcal

2.3. Comparison Data Set

Several sources were found that provided individual measures of RMR_S as well as measures of or means of computing BSA, W, G, A, FFM, and FM (Bessard et al., 1983; Owen et al., 1986; Owen et al., 1987; Ravussin et al., 1982; Weststrate et al., 1989). Obese subjects (PF greater than 25 in men or greater than 30 in women) and subjects younger than 18 or older than 55 yrs were excluded. The total number of data records was 86. Although there are a few athletes in the data set, most of the subjects would be considered sedentary. When it was necessary to compute subject characteristics (e.g., to compute H from BMI and W), the following relationships were used:

$$BMI = W/H^2$$
$$LBMe\ (men) = (79.5 - 0.24W - 0.15A)/73.2$$
$$LBMe\ (women) = (69.8 - 0.26W - 0.12A)/73.2$$
$$BSA = 0.007184 \cdot W^{0.425} H^{0.725}$$

The formula for LBMe was provided by Cunningham (1980). Body surface area (BSA) is computed using the classic formulation from Dubois and Dubois (1916).

2.4. Equations for Estimating RMR_S

We found several equations for estimating RMR_S in the literature that used combinations of BSA, W, H, A, G, FFM, FM and LBMe as independent variables (Boothby, 1936; Cunningham, 1980; Harris and Benedict, 1919; Hayter and Henry, 1994; Klausen et al., 1997; Mifflin et al., 1990; Nelson et al., 1992; Owen et al., 1986; Owen et al., 1987; Robertson and Reid, 1952; Schofield, 1985). When the authors provided multiple equations, the most appropriate equations for the subjects in the comparison data set were selected. Data from Robertson and Reid (1952) were reanalyzed using only subjects aged 17-55 and simple linear regression on age (higher order exponentials not included). Data from Owen et al. (1986 and 1987) were also reanalyzed; data from all women were combined to form a single equation for

women, and the term FM (which contributed significantly) was added to the equation for the men.

2.5. Linear Regression Analysis on the Comparison Data Set

Linear regression analysis was conducted on the comparison data set using W, H, A, G, BSA, LBMe, FFM, FM as well as W raised to powers of 2/3 and 3/4 as independent variables. P values less than 0.05 were considered significant. The standard error of the estimate (SEE) was used to assess goodness of fit. The difference (Δ) between estimated and measured values (mean, standard deviation and range) were used to identify the degree to which the equation consistently under- or overestimated the data.

3. Results

3.1. Comparison Data Set

Summary characteristics of the comparison data set are presented in the table below.

Table 2. Characteristics of the Comparison Data Set

Symbol	*Males (55)*	*Females (31)*	*Combined (86)*
W (kg)	76.4±12.46	55.9±5.33	69.0±14.37
H (cm)	177.0±7.28	164.5±5.92	172.5±9.07
A (yr)	31.5±12.90	27.7±7.31	30.1±11.30
PF (%)	16.4±4.80	21.0±4.78	18.1±5.25
FFM (kg)	63.62±9.04	44.1±4.89	56.6±12.2
LBMe (kg)	58.4±5.90	39.6±2.82	51.6±10.38
FM (kg)	12.8±5.26	11.7±2.97	12.4±4.58
BSA (m^2)	1.93±0.16	1.61±0.099	1.81±0.21
BMI (kg/m^2)	24.38±3.54	20.6±1.46	23.0±3.46
RMR_S (kcal/h)	70.2±10.22	50.32±6.35	63.0±13.14

3.2. Comparisons Between Measured and Estimated RMR_S

Equations for estimating RMR_S, as well as results of comparisons between estimated and measured RMR_S, are provided in Table 3. Almost all of the equations overestimated RMR_S, with overestimation ranging from 0.6 kcal/h (0.9%) to 12.7 kcal/h (20.2%). Only one set of equations (Owen et al., 1986-1987) under-predicted RMR for the comparison data set (by 0.2 kcal/h or 0.3%). The Owen et al. (1986-1987), Mifflin et al. (1990) and Nelson et al. (1992) equations provided the best fit to the data in the comparison data set. The equation for $RMR_{standing}$, used to represent all resting activity in the USARIEM Heat Stress and Scenario models understandably did poorly at estimating RMR_S (measured in the supine position, in the morning, in the fasted state) for the comparison data set (SEE=28.5, Δ=26.0±11.0). The Harris and Benedict (1919) equations, used by the Combat Feeding Program's nutrition models (REAP, ROPE, RASP, DYNUMO) performed better (SEE =8.8, Δ=5.2±7.1), but not as well as the Owen et al., Mifflin et al. and Nelson et al. equations.

Table 3. Equations and Comparisons Between Estimated and Measured Values of RMR_S

Source		*Equations*	*Statistics*
*USARIEM Heat Stress and SCENARIO Models		$RMR_{standing} = 1.5*W$	SEE: 28.5 Δ: 26.0±11.0 (-16.9,30.4)
Harris and Benedict, 1919	men: women:	$RMR_S = 2.768 + (0.5730)W + (0.2085)H - (0.2815)A$ $RMR_S = 27.30 + (0.3985)W + (0.07707)H - (0.1948)A$	SEE: 8.8 Δ: 5.2±7.1 (-20.7,22.6)
Boothby, 1936		$RMR_S = [44.71 - (0.15066)A]*BSA$ $RMR_S = [38.14 - (0.07511)A]*BSA$	SEE: 10.1 Δ: 7.2±7.0 (-18.9,26.0)
**Robertson and Reid, 1952	men: women:	$RMR_S = [40.85 - 0.1384\ A]*BSA$ $RMR_S = [36.47 - 0.09198\ A]*BSA$	SEE: 7.4 Δ: 1.7±7.2 (-25.1,18.7)
Cunningham, 1980		$RMR_S = 20.9 + 0.9*LBMe$ men: $LBMe = (79.5 - 0.24\ W - 0.15\ A)\ W/73.2$ women: $LBMe = (69.8 - 0.26\ W - 0.12\ A)\ W/73.2$	SEE: 8.3 Δ: 4.3±7.0 (-17.9,19.9)
Schofield, 1985	men: women:	$RMR_S = 0.627W + 28.82$ $RMR_S = 0.617W + 20.26$	SEE: 8.3 Δ: 4.6±6.8 (-18.1,21.9)
***Owen et al., 1986-1987	men: women:	$RMR_S = 19.32 + 0.753\ FFM + 0.211\ FM$ $RMR_S = -48.838 + 0.262\ W + 0.514\ H$	SEE: 6.6 Δ: -0.2±6.6 (-22.1,17.8)
Mifflin et al., 1990		$RMR_S = 17.2 + 0.82\ FFM$	SEE: 7.0 Δ: 0.6±6.9 (-23.2,16.6)
Nelson et al., 1992		$RMR_S = 11.09 + (0.900)\ FFM + (0.1314)\ FM$	SEE: 6.9 Δ: 0.6±6.8 (-22.5,17.6)
Hayter and Henry, 1994	men: women:	$RMR_S = 0.51W + 34.83$ $RMR_S = 0.47W + 28.66$	SEE: 8.2 Δ: 4.0±8.2 (-17.2,22.9)
Klausen et al. 1997		$RMR_S = 14.211 + (1.087)FFM$	SEE: 14.7 Δ: 12.7±7.1 (-9.9,30.4)

* Equations for resting metabolic rate used by these models refer to a standing subject. However, these are the only equations in the models to describe the resting state (there are no equations for sleeping, sitting, etc.) so these are included here.
** Data from Robertson and Reid, 1952 were reanalyzed. Data from subjects aged 17-55 were included for each gender. Simple linear regression on age was performed (higher order exponentials were not included).
***Data from Owen et al., 1986-87 were reanalyzed. Data from all women were combined to form the first equation, and the term FM (which contributed significantly) was added to the equation for the men.

The mean difference between estimated and measured values of RMR_S (Δ) was close to zero for only a few of the equations. For the remaining, there were at times large discrepancies between the average estimated and measured values. Table 4 shows the results of adjusting each equation by the corresponding Δ value from Table 3. When this adjustment is made, apparent differences in prediction power among the equations were greatly reduced. With the exception of the equation for $RMR_{standing}$, SEE values ranged from 6.6 to 7.2 kcal/h with a similar range of differences between predicted and measured values. Eliminating the adjusted Owen et al. (1986-1987) and Nelson et al. (1992) equations from consideration because they contain much of the same data as the comparison data set, the adjusted Schofield equation, did slightly better than the

other equations (SEE=6.8, Δrange -22.7 to 17.3 in kcal/h). The adjusted Harris and Benedict equations did somewhat less well (SEE=8.8), while the adjusted equation for $RMR_{standing}$ continued to perform poorly (SEE=11.1).

Table 4. Adjusted RMR Equations and Comparisons Between Estimated and Measured Values of RMR

Source		*Equations*	*Statistics*
USARIEM Heat Stress and SCENARIO Models		$RMR_{standing}$ = 1.5*W – 26.0	SEE: 11.1 Δ: 0.0±11.0 (-19.7,40.2)
Harris and Benedict (1919)	men: women:	RMR = -2.432 + (0.5730)W + (0.2085)H - (0.2815)A RMR = 22.10 + (0.3985)W + (0.07707)H - (0.1948)A	SEE: 7.1 Δ: 0.0±7.1 (-25.9,17.4)
Boothby, 1936	men: women:	RMR =[44.71 – (0.15066)A]*BSA-7.2 RMR =[38.14 – (0.07511)A]*BSA-7.2	SEE: 7.1 Δ: 0.0±7.0 (-26.1,18.8)
Robertson and Reid, 1952	men: women:	RMR =[40.85 – 0.1384 A]*BSA-1.7 RMR =[36.47 – 0.09198 A]*BSA-1.7	SEE: 7.2 Δ: 0.0±7.2 (-26.18,17.0)
Cunningham, 1980		RMR = 20.9 + 0.9*LBMe – 4.3 men: LBMe= (79.5 – 0.24 W – 0.15 A) W/73.2 women: LBMe= (69.8 – 0.26 W – 0.12 A) W/73.2	SEE: 7.1 Δ: 0.0±7.0 (-22.2,15.6)
Schofield, 1985	men: women:	RMR=0.627W+28.82 – 4.6 RMR=0.617W+20.26 – 4.6	SEE: 6.8 Δ: 0.0±6.8 (-22.7,17.3)
Owen et al., 1986-1987	men: women:	RMR = 19.32 + 0.753 FFM + 0.211 FM + 0.2 RMR = -48.838+0.262 W+0.514 H + 0.2	SEE: 6.6 Δ: 0.0±6.6 (-21.9,18.0)
Mifflin et al., 1990		RMR = 17.2 + 0.82 FFM – 0.6	SEE: 7.0 Δ: 0.0±6.9 (-23.8,16.0)
Nelson et al., 1992		RMR = 11.09 + (0.900) FFM + (0.1314) FM – 0.6	SEE: 6.9 Δ: 0.0±6.8 (-23.1,17.0)
Hayter and Henry, 1994	men: women:	RMR=0.51W+34.83 – 4.0 RMR=0.47W+28.66 – 4.0	SEE: 7.1 Δ: 0.0±7.1 (-21.2,18.9)
Klausen et al. 1997		RMR=14.211+(1.087)FFM -12.7	SEE: 7.1 Δ: 0.0±7.1 (-22.6,17.7)

3.3. Linear Regression on Comparison Data Set

Results of linear correlation with RMR for the comparison data set are shown in Table 5, ordered from highest to lowest r value. The variable with the highest correlation coefficient was LBMe, computed using A, G, and BW, followed closely by FFM, then W. Powers of W to the 2/3 or 3/4 had slightly higher correlation coefficients than W alone.

Table 5. Results of Correlation Analyses

Variable	*r*	*Variable*	*r*
LBMe	0.858665	W	0.811876
$FFM^{2/3}$	0.85694	G (1=M, 2=F)	-0.73015
$FFM^{3/4}$	0.856736	H	0.665355
FFM	0.855497	PF	-0.31023
BSA	0.824809	FM	0.276887
$W^{2/3}$	0.820742	A	-0.05718
$W^{3/4}$	0.818746		

Results of linear regression on the comparison data set are shown in Table 6. W, H, A, G, LBMe, FFM, FM, BSA, and W to powers of 2/3 and 3/4 were used as independent variables. Use of $W^{2/3}$ or $W^{3/4}$ did not improve the fit substantially compared to W alone. Use of FFM and FM was not a better combination than of W, A and G. The best fit was provided by a combination of LBMe and G and a combination of W, A and G (SEE=6.75 in both cases).

Table 6. Results of Linear Regression Analyses

Equation	*SEE*	*Nonsignificant Terms*
1.216·LBMe	6.87	C, A
1.167·LBMe + 2.061·G	6.75	
1.105·FFM	7.18	FM, A, G
10.91+0.921·FFM	6.85	FM, A, G
0.906·W	8.04	A, G
0.683·W+0.092·H	7.60	
11.78+0.742·W	7.72	
-27.94+0.619·W+0.279·H	7.54	A
37.98+-8.862·G+0.538·W	7.10	H
45.23-9.624·G+0.537·W-0.206·A	6.75	
$3.791 \cdot W^{2/3}$	7.83	
$-16.46+4.759 \cdot W^{2/3}$	7.55	
$2.649 \cdot W^{3/4}$	7.62	C
34.980·BSA	8.21	
38.007·BSA-0.184·A	7.97	
42.043·BSA-0.144·A-6.546·G	6.96	C
-30.28+51.457·BSA	7.48	G, A

4. Discussion

4.1. Comparisons Between Estimates of RMR and Measured Values

Most of the equations for estimating RMR_S evaluated in this report overestimated RMR_S for the comparison data set. Other evaluations comparing estimates obtained using these equations with measured RMR values from contemporary subjects, also demonstrate a tendency for the equations to overestimate RMR (Azcue et al., 1991; Censi et al., 1998; Clark and Hoffer, 1991; Daly et al., 1985; Garrel et al., 1996; Mifflin et al., 1990; Owen et al., 1986-1987; Piers et al., 1997). Two exceptions are from studies conducted using highly trained athletes as test subjects (Delorenzo et al., 1999; Thompson and Manore, 1996). In both of these studies, published equations under-predicted measured RMR values. As a reference, the Mifflin et al. equations underestimated data for men in the Thompson and Manore study by 11% and the women by 12.4%. Although the athletes were required to refrain from exercise for 12 or 36 hours, this may not have been long enough to rule out possible residual effects of physical activity on RMR (discussed below). Also, it is possible that while the athletes refrained from exercise, they did not immediately adjust their food intake so that they were in a positive energy balance. The effects of the analysis are also discussed below.

In the initial analyses, three equations provided a good fit to the data: the Owen et al. (1986-1987), Mifflin et al. (1990) and Nelson et al. (1992) equations. Because the Owen et al. and Nelson et al. equations were developed using some of the same data as in the comparison data set, we decided to eliminate these from consideration. Therefore, the Mifflin et al. (1990) equation was selected as providing the best fit to the comparison data set. In the follow-on analysis, using equations adjusted by the average Δ value from the first analyses, the adjusted Schofield (1985) equations, which use W and G as independent variables, provided the best fit.

4.2. Linear Regression Using the Comparison Data Set

Previously published equations tend to use one of 4 distinct sets of independent variables. These are: (1) BSA, (2) W raised to some power, (3) W with and without H, A, and G, and (4) FFM with and without FM. According to Harris and Benedict (1919), the origin of the use of BSA is due to the hypothesis that the body temperature for homeotherms is constant and the same across species so that heat production must be proportional to heat loss from the body surface, which is largely a function of the body surface area. This theory was largely put to rest when it was shown that animals tend to compensate for differences between metabolic heat production and heat loss through behavioral and other adaptive mechanisms. Meanwhile, comparative studies tend to show that increases in body size are associated with a decrease in the RMR per kg BM. This influence of body size was found, over a wide variety of animal species, to be best expressed in the form $RMR = a \cdot W^b$, where b is generally found to be between 2/3 and 3/4. There does not appear to be any plausible biological explanation for this value of 2/3-3/4. Except for the Boothby (1936) equations, all of the equations evaluated in this report use combinations of W, H, A, and G, or FFM and FM. The argument for FFM over W, H, A and G is that the metabolic contribution of the FM is very small compared to that of the FFM and that use of FFM often eliminates the need to consider separate subpopulations grouped by age or gender. In a few studies, use of FM was found to provide a slightly better fit than use of FFM alone (Nelson et al., 1992; Owen et al., 1986-1987). The main advantage of using FFM and FM as independent variables is that the resulting regression coefficients should make sense

physiologically. The constant coefficient should account for that portion of the RMR not related to body mass, the coefficient in front of FM should be roughly the average metabolic rate of adipose tissue, while the coefficient associated with FFM should account for what remains. Without a constant term, the coefficient associated with FFM should be roughly the weighted average of tissue metabolic rates making up the fat-free tissue. Theoretically, then, coefficients could be derived from measured tissue metabolic rates and body composition. The greatest disadvantage of the use of FFM is that its measurement requires specialized equipment, so obtaining FFM values to use in the RMR_S equation is not as simple as obtaining W, H, A and G.

Results of regression analyses performed on the comparison data set showed relatively high SEE values when BSA was used as the independent variable. There was no clear advantage of using W raised to a power over W alone. The best fit was obtained using combinations of W, G and A (*note: LBMe is computed using W, A, and G*). Use of FFM (without FM) provided almost as good a fit. It is possible that the reason for the closeness in results, insignificance of FM may have been due to the sample population in the comparison data set, in which data from obese subjects was excluded.

4.3. Accounting for Physical Activity and Energy Balance

One of the primary differences between the comparison data set and active duty military, as a group, is the average activity level. Exercise and other physical activity have been shown to increase RMR for up to 48 hours (Williamson and Kirwan, 1997). Bielitzki et al. (1985) showed a 4.7% increase in RMR following 3 hours of exercise at 50% of VO_{2max} the previous day. Maehlum et al. (1986) found an increase in RMR of approximately 14% 12 hours post-exercise. Tremblay et al. (1988) showed a 6.6% decrease in RMR after 3 days of detraining. Sedlock et al., (1989) found that exercise intensity affects both the magnitude and duration of the RMR increase, while exercise duration affected only duration of the RMR increase. Weststrate and Hautvast (1990) found that glycogen depletion caused an increase in RMR of 9% the following day. Goldberg et al. (1990) found that sleeping and basal metabolic rates on the night following exercise were raised (5.8% and 3.9%, respectively, following 2 hr exercise at 60% of VO_{2max} the preceding day) and that there was an almost linear-dose response relationship with no evidence of a threshold. Thompson and Manore (1996), in attempting to explain the high RMR values found in their highly-trained athletes (even after adjusting for body composition), found that energy intake, energy balance, VO_{2max} and free thyroxine levels could account for a large portion of the variance in RMR. Williamson and Kirwan (1997) found that an acute bout of resistance exercise caused a sustained increase in BMR of approximately 3.3% that persisted for up to 48 hours after exercise.

While there are insufficient data to develop quantitative relationships between daily activity level and subsequent RMR, using the difference between subjects in the Mifflin et al. (1990) and Thompson and Manore (1996) studies, we propose an upper limit on the effects of "very high" levels of prior physical activity on RMR_S of +12% compared to prior sedentary activity. Based on differences in RMR between the Mifflin et al. (1990) and Harris and Benedict (1919) subjects, we would propose that the effect of moderate levels of physical activity (consistent with a normal lifestyle in 1919) would be approximately 6%. Starting with the unadjusted Schofield equation to represent moderately active individuals (e.g., typical active-duty military) the effects of PA can be incorporated by a decrease or increase in RMR of 6% to

represent sedentary and highly active (e.g., athletes in training, warfighters during high-tempo operations) subjects, respectively:

men: $RMR_S = (1 + 0.06 \cdot PA) \cdot (0.627 \cdot W + 24.22)$

women: $RMR_S = (1 + 0.06 \cdot PA) \cdot (0.617 \cdot W + 15.66)$

where PA is prior activity, a value of -1 representing "sedentary", 0 representing "moderately active", and +1 representing "highly active".

RMR_S is also modulated by the amount of calories consumed in the diet relative to energy expenditure. Severe undernutrition results in a decrease in RMR_S (Bullough et al., 1995; Goran et al., 1994; Hill et al., 1987; Ravussin et al., 1985; Mole et al., 1989; Weinsier et al., 2000) while overnutrition results in an increase in RMR_S (Bullough et al., 1995; Goran et al., 1994; Shutz et al., 1985; Welle and Campbell, 1983). Whether exercise can reverse changes in RMR resulting from undernutrition (Mole et al., 1989) may depend on the degree of undernutrition (van Zant, 1992). Also, in some cases the observed decline in RMR_S during hypocaloria may be at least partially accounted for by changes in FFM (Ravussin et al., 1985). While warfighters are periodically subjected to periods of undernutrition, especially during high-tempo operations and training missions, activity levels are also generally very high, which should offset any changes in RMR_S. Therefore, this effect is not accounted for at this time.

4.4. Accounting for Fitness and Training

The other primary differences between subjects in the comparison data set and active duty military is the average fitness level; subjects in the comparison data set come from a healthy, but largely sedentary population, whereas active duty military are required to maintain a minimum level of physical fitness (as assessed by biannual physical fitness testing) and many are required, by job demands, to maintain a very high level of physical fitness. Many studies show an increase in RMR_S following physical training. As previously mentioned, increased FFM and prior exercise, which usually accompany a training regimen, may also increase RMR_S, so separating out the various effects is difficult. To aid in this process, studies were reviewed that controlled the time between testing and prior exercise or that restricted exercise for at least 48 hours prior to testing.

In a study by Ravussin and Bogardus (1989) subjects (Pima Indians) refrained from exercise for 7 days prior to testing. VO_{2max} varied between 27 and 74 ml O_2/kg FFM/min, but was found to be unrelated to RMR_S. In another study using 20 well-trained male athletes and 43 untrained subjects matched for W, FFM and A (Schulz et al., 1991), there was no difference in RMR_S when subjects were kept in the testing ward for 2 days prior to testing during which time only light activity was allowed. Broeder et al. (1992) found that RMR_S was not significantly different between trained and untrained individuals when subjects refrained from exercise for at least 48 hours prior to the test session and RMR_S was expressed per kg FFM or FFM was used as a covariate (F ratio = 0.353, P less than 0.70). Wilmore et al. (1998) found no difference in RMR_S measured pre- and post-training when the time between testing and previous exercise bouts (24 or 72 h prior to testing) was controlled.

From the results of these studies, we can conclude that physical fitness and training do not affect RMR_S, once the effects of FFM and prior exercise have been accounted for.

4.5. Effects of Subjective Time of Day

We have defined the Standard Resting Metabolic Rate (RMR_S) as that occurring in the morning after an overnight fast, with the subject in a reclined or semi-reclined position, and free of physical or mental tension. There is a true circadian rhythm of oxygen consumption and this rhythm is, at least partly, independent of food intake and activity (Aschoff and Pohl, 1970). In a constant environment during the follicular phase of the menstrual cycle, women show a circadian amplitude of approximately 45 ml O_2/min, or approximately 12 kcal/h, amounting to approximately 16% of the RMR (Aschoff and Pohl, 1970, Fig 13). However, most of the change in RMR appeared to occur between 10:00 PM and 8:00 AM; circadian changes in RMR during the daytime hours appeared minor. Other researchers have found smaller, albeit significant, changes associated with time of day of measurement once the effects of activity and feeding have been accounted for. Zurlo et al. (1986) studied 9 subjects under 2 nutritional conditions: enteral-feeding of a mixed diet at an energy level corresponding to 1.44*RMR, and fasting. The intraindividual variability of RMR throughout the day (expressed as the coefficient of variation) ranged from 0.7% to 2% in the fasting condition and 1.2% to 4.1% in the fed condition. However, there was no difference between the RMR measured in the morning vs. afternoon. Weststrate et al. (1989) also failed to detect a circadian rhythm in RMR. In contrast, Haugen et al. (2003) found that afternoon RMR was significantly higher than RMR measured in the morning, when both measurements were made 12 hours post meal and 12 hours post exercise. The mean difference was 99.0 ± 35.8 kcal/d or approximately 6%.

There is currently not enough data to quantify the circadian rhythm in resting metabolic rate. Even if we were able to do so, subjective time of day is likely to vary under conditions of sleep restriction, which is a reality during many operational scenarios. For these reasons, circadian effects (although possibly significant) would need to be handled using a model of circadian/sleep/wake rhythm and cannot be taken into account at this time.

4.6. Effects of Body Temperature and Heat Acclimation on Metabolic Rate

Goldman (1978) reviewed the effects of environmental temperature on RMR and found: (1) that an increase in deep body core temperature of 1 °C, whether due to febrile disease or increased body heat storage, can increase the metabolic rate by 12%; (2) that the increase in muscle tone that precedes shivering in the cold can substantially increase oxygen consumption; (3) that voluntary isometric contraction can increase heat production by 36% and (4) that shivering can increase RMR to 425 kcal/h, 500% of the normothermic RMR. Even without muscle contraction or shivering, cooler temperatures at the low end of a person's thermoneutral zone can significantly increase RMR. Daucy (1981) found an increase in fasted RMR of 7.0 ± 1.1% in women with a fall in environmental temperature from 28 °C to 22 °C wearing identical clothing and no apparent signs of shivering. Blaza and Garrow (1983) found an increase of 99 kcal/d (7.8%) at the lower end of the thermoneutral zone in their female subjects (23.3 °C) and an increase of 8.5 kcal/d (0.6%) at the upper end (26.2 °C) compared to the 24-hour energy expenditure of 1273 kcal/d during the control experiment (in the center of the thermoneutral zone).

Although cooling body temperatures can account for a significant increase in RMR, the interaction between metabolic rate and body temperature (i.e., metabolic rate determines body temperature which determines shivering and non-shivering thermogenesis) is best handled within a model of human thermoregulation. Recommendations in this report will, therefore, refrain from the inclusion of environmental effects on metabolic rates.

4.7. Effects of Energy Consumption

The thermic effect of feeding (TEF) accounts for the energy required to digest, absorb, transport and metabolize ingested nutrients. Although the TEF is measured as the difference between postprandial metabolic rate and fasted metabolic rate under otherwise similar conditions, it is often expressed as a percentage of the total ingested metabolizable energy. The TEF is influenced by a number of factors including the caloric content and composition of the meal (Acheson et al., 1984; Jequier and Schultz, 1983) and can account for up to 10% of the total daily energy expenditure. Bennet and Hicks (2001) showed that the TEF and thermic effects of physical activity (TEA) were additive (i.e., total metabolic rate was the sum of RMR_S, TEA and TEF). In other words, the TEF was not reduced by competing demands of exercise. Zurlo et al. (1986) found that mean postprandial thermogenesis measured over 30 minutes was 4.9±0.4% of delivered metabolizable energy. Armellini et al. (2000) found a higher percentage of TEF (12-14% of the energy content of the meal) when TEF was measured over 6 hours. Bessard et al. (1983) measured TEF at 9.5% in control subjects over a 300-minute observation period. Although there were insufficient data to develop an accurate model of TEF, based on these results, a rough approximation was derived assuming a linear-exponential function of TEF over time (i.e., $TEF = a \cdot t/b^t$), a peak at 1 hour and a total area under the curve of 14% of the ingested, metabolizable caloric content of the meal:

$$TEF = (0.02376 \cdot t/1.0168^t) \cdot FEC/100$$

where t is the time since meal ingestion in minutes, and FEC is the food energy content in kcal. According to this formula, at 60 minutes, the TEF would be 2.6 kcal/h when FEC = 500 kcal, or about 4% of RMR_S (fasted).

4.8. Effects of Anxiety/Stress

Schmidt et al (1996) investigated relationships between anxiety and RMR. They found that among seventy-nine male college students, that RMR was higher in high-trait anxious group than in the low-trait anxious group as measured using the State-Trait Anxiety Inventory. They concluded that a statistically significant portion of the variance in RMR could be accounted for by individual differences in anxiety. The difference in RMR between groups, after adjusting for FFM, was approximately 9%. While this study identifies differences between inherently nervous individuals vs. low-anxiety normals, it does not necessarily lead to conclusions regarding the effect of anxiety-provoking stimuli on normal subjects.

Weststrate et al. (1990) studied the effects of anxiety-producing stimuli on RMR. In this, case subjects watched either a stress-inducing horror film or a romantic family film. The authors found that the type of film shown to the subjects (the horror film intended to induce anxiety) had no effect on RMR. Based on this result, and difficulty in quantifying stress as an input variable, we recommend ignoring the effects of anxiety or stress on RMR for the time being.

5. Conclusions

In this report, we evaluated several published equations for estimating RMR_S and reviewed studies on the effect of various factors on RMR to determine the best method to estimate RMR in the warfighter given our current available knowledge. We determined that once inherent differences in the subject populations used to develop and test the equations were considered, that the Schofield Equations provided the best fit to the data. We developed rough approximations for accounting for prior activity and the thermic effect of food on RMR, determined that effects of physical training and anxiety were likely negligible and that circadian and environmental effects would be best handled by circadian and thermoregulatory models. The final relationships for estimating RMR of the warfighter are provided below.

$$RMR = RMR_S + TEF$$

where

$$TEF = (0.02376 \cdot t / 1.0168^t) \cdot FEC/100$$

men: $$RMR_S = (1 + 0.06 \cdot PA) \cdot (0.627 \cdot W + 24.22)$$

women: $$RMR_S = (1 + 0.06 \cdot PA) \cdot (0.617 \cdot W + 15.66)$$

The results of this study should be verified using a comparison data set more representative of active duty military than the one used in this report.

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References

Acheson, K.J.; Schutz, Y.; Bessard, T.; Ravussin, E.; Jequier, E.; Flatt, J.P. Nutritional influences on lipogenesis and thermogenesis after a carbohydrate meal. Am J Physiol 246(1 Pt 1):E62-70, 1984.

Armellini, F.; Zamboni, M.; Mino, A.; Bissoli, L.; Micciolo, R.; Bosello, O. Post-absorptive resting metabolic rate and thermic effect of food in relation to body composition and adipose tissue distribution. Metabolism 49(1):6-10, 2000.

Aschoff, J.; Pohl, H. Rhythmic variations in energy metabolism. Fed Proc 29:1541, 1970.

Azcue, M.P.; Pencharz, P.B.; Zello, G.A. Are the FAO/WHO/UNU predictive equations for resting metabolic rate accurate? [letter; comment]. Am J Clin Nutr 54(3):613-4, 1991.

Bennett, A.F.; Hicks, J.W. Postprandial exercise: prioritization or additivity of the metabolic responses? J Exp Biol 204(Pt 12):2127-32, 2001.

Bessard, T.; Schutz, Y.; Jequier, E. Energy expenditure and postprandial thermogenesis in obese women before and after weight loss. Am J Clin Nutr 38(5):680-93, 1983.

Bielinski R.; Schutz, Y.; Jequier, E. Energy metabolism during the post-exercise recovery in man. Am J Clin Nutr 42(1):69-82,1985.

Black, A.E.; Coward, W.A.; Cole, T.J.; Prentice, A.M. Human energy expenditure in affluent societies: an analysis of 574 doubly-labelled water measurements. Eur J Clin Nutr 50(2):72-92, 1996.

Blaza, S.; Garrow, J.S. Thermogenic response to temperature, exercise and food structure in lean and obese women, studies by 24 h direct calorimetry. Br J Nutr 49:171-180, 1983

Boothby, W.M.; Berkson, J.; Dunn, H.L. Studies of the energy metabolism of normal individuals: a standard for basal metabolism, with a normogram for clinical application. Am J Physiol 116:468-484, 1936.

Broeder, C.E.; Burrhus, K.A.; Svanevik,L.S.; Wilmore, J.H. The effects of aerobic fitness on resting metabolic rate. Am J Clin Nutr 55(4):795-801, 1992.

Bullough, R.C.; Gillette, C.A.; Harris, M.A.; Melby, C. Interaction of acute changes in exercise energy expenditure and energy intake on resting metabolic rate. Am J Clin Nutr 61(3):473-81, 1995.

Censi, L.; Toti, E.; Pastore, G.; Ferro-Luzzi, A. The basal metabolic rate and energy cost of standardised walking of short and tall men. Eur J Clin Nutr 52(6):441-446, 1998.

Clark, H.D.; Hoffer, L.J. Reappraisal of the resting metabolic rate of normal young men. Am J Clin Nutr 53(1):21-26, 1991.

Cunningham, J.L. A reanalysis of the factors influencing basal metabolic rate in normal adults. Am J Clin Nutr 33:2372-2374, 1980.

Daly, J.M.; Heymsfield, S.B.; Head, C.A.; Harvey, L.P.; Nixon, D.W.; Katzeff, H.; Grossman, G.D. Human energy requirements: overestimation by widely used prediction equation. Am J Clin Nutr 42:1170-1174, 1985.

Dauncey, M.J. Influence of mild cold on 24 h energy expenditure, resting metabolism and diet induced thermogenesis. Br J Nutr 45:257-267, 1981.

De Lorenzo, A.; Bertini, I.; Candeloro, N.; Piccinelli, R.; Innocente, I.; Brancati, A. A new predictive equation to calculate resting metabolic rate in athletes. Journal of Sports Med Phys Fitness 39(3):213-9, 1999.

DuBois, D.; DuBois, E.F. Clinical Calorimetry X. Arch Int Med 17:863, 1916.

Garrel, DR.; Jobin, N.; de Jonge, L.H. Should we still use the Harris and Benedict equations? Nutrition in Clinical Practice 11(3):99-103, 1996.

Goldberg, G.R.; Prentice, A.M.; Davies, H.L.; Murgatroyd, P.R. Residual effect of graded levels of exercise on metabolic rate. Eur J Clin Nutr 44(2):99-105, 1990.

Goldman, R.F. Effect of environment on metabolism. Proceedings: First Ross Conference on Metabolism, Jackson Point, ME, June 1978.

Goran, M.I.; Calles-Escandon, J.; Poehlman, E.T.; O'Connell, M.; Danforth, E. Jr. Effects of increased energy intake and/or physical activity on energy expenditure in young healthy men. J Appl Physiol 77(1):366-72, 1994.

Harris, J.A.; Benedict, F.G. A biometric study of basal metabolism in man. Washington, D.C.: The Carnegie Institute, 1-266, 1919.

Haugen, H.A.; Melanson, E.L.; Tran, Z.V.; Kearney, J.T.; Hill, J.O. Variability of measured resting metabolic rate. Am J Clin Nutr 78(6):1141-5, 2003.

Hayter, J.E.; Henry,C.J. A re-examination of basal metabolic rate predictive equations: the importance of geographic origin of subjects in sample selection. Eur J Clin Nutr 48(10):702-707, 1994.

Hill, J.O.; Sparling, P.B.; Shields, T.W.; Heller, P.A. Effects of exercise and food restriction on body composition and metabolic rate in obese women. Am J Clin Nutr 46(4):622-30, 1987.

Jequier, E.; Schutz, Y. Long-term measurements of energy expenditure in humans using a respiration chamber. Am J Clin Nutr 38(6):989-98, 1983.

Klausen, B.; Toubro, S.; Astrup, A. Age and sex effects on energy expenditure. Am J Clin Nutr 65(4):895-907, 1997.

Maehlum, S.; Grandmontagne, M.; Newsholme, E.A.; Sejersted, O.M. Magnitude and duration of excess post-exercise oxygen consumption in healthy young subjects. Metabolism 35(5):425-9, 1986.

Mifflin, M.D.; St Jeor, S.T.; Hill, L.A.; Scott, B.J.; Daugherty, S.A.; Koh, Y.O. A new predictive equation for resting energy expenditure in healthy individuals. Am J Clin Nutr 51(2):241-7, 1990.

Mole, P.A.; Stern, J.S.; Schultz, C.L.; Bernauer, E.M.; Holcomb, B.J. Exercise reverses depressed metabolic rate produced by severe caloric restriction. Med Sci Sports Exerc 21(1):29-33, 1989.

Nelson, K.M.; Weinsier, R.L.; Long,C.L.; Schutz, Y. Prediction of resting energy expenditure from fat-free mass and fat mass. Am J Clin Nutr 56(5):848-56, 1992.

Owen, M.D.; Kregel, K.C.; Wall, P.T.; Gisolfi, C.V. Effects of ingesting carbohydrate beverages during exercise in the heat. Med Sci Sports Exerc 18(5):568-75, 1986.

Owen, O.E.; Holup, J.L.; D'Alessio, D.A.; Craig, E.S.; Polansky, M.; Smalley, K.J.; Kavle, E.C.; Bushman, M.C.; Owen, L.R.; Mozzoli, M.A.; et al. A reappraisal of the caloric requirements of men. Am J Clin Nutr 46:875-885, 1987.

Piers, L.S.; Diffey, B.; Soares, M.J.; Frandsen,S.L.; McCormack,L.M.; Lutschini,M.J.; O'Dea, K. The validity of predicting the basal metabolic rate of young Australian men and women. Eur J Clin Nutr 51(5):333-7, 1997.

Ravussin, E.; Bogardus, C. Relationship of genetics, age and physical fitness to daily energy expenditure and fuel utilization. Am J Clin Nutr 49:968-975, 1989.

Ravussin, E.; Burnand, B.; Schutz, Y.; Jequier, E. Twenty-four hour energy expenditure and resting metabolic rate in obese, moderately obese, and control subjects. Am J Clin Nutr 35:566-573, 1982.

Ravussin, E.; Burnand, B.; Schutz, Y.; Jequier, E. Energy expenditure before and during energy restriction in obese patients. Am J Clin Nutr 41(4):753-9, 1985.

Robertson, J.D.; Reid, D.D. Standards of basal metabolism. Lancet 1:940-943, 1952.

Schmidt, W.D.; O'Connor, P.J.; Cochrane, J.B.; Cantwell, M. Resting metabolic rate is influenced by anxiety in college men. J Appl Physiol 80(2):638-42, 1996.

Schofield, W.N. Predicting basal metabolic rate, new standards and review of previous work. Hum Nutr Clin Nutr 39C(Suppl 1):5-41, 1985.

Schulz, L.O.; Nyomba,B.L.; Alger,S.; Anderson,T.E.; Ravussin, E. Effect of endurance training on sedentary energy expenditure measured in a respiratory chamber. Am J Physiol 260(2Pt 1):E257-267, 1991.

Schutz, Y.; Acheson, K.J.; Jequier, E. Twenty-four-hour energy expenditure and thermogenesis: response to progressive carbohydrate overfeeding in man. Int J Obes 9 Suppl 2:111-4, 1985.

Sedlock, D.A.; Fissinger, J.A.; Melby, C.L. Effect of exercise intensity and duration on post-exercise energy expenditure. Med Sci Sports Exerc 21(6):662-6, 1989.

Thompson, J.; Manore, M.M. Predicted and measured resting metabolic rate of male and female endurance athletes. J Am Diet Assoc 96(1):30-4, 1996.

Tremblay, A.; Nadeau, A.; Fournier, G.; Bouchard, C. Effect of a three-day interruption of exercise training on resting metabolic rate and glucose-induced thermogenesis in training individuals. Int J Obes 12(2):163-168, 1988.

Van Zant, R.S. Influence of diet and exercise on energy expenditure-a review. International Journal of Sports Nutrition 2(1):1-19, 1992.

Weinsier, R.L.; Nagy, T.R.; Hunter, G.R.; Darnell, B.E.; Hensrud, D.D.; Weiss, H.L. Do adaptive changes in metabolic rate favor weight regain in weight-reduced individuals? An examination of the set-point theory. Am J Clin Nutr 72(5):1088-94, 2000.

Welle, S.; Campbell, R.G. Stimulation of thermogenesis by carbohydrate overfeeding. Evidence against sympathetic nervous system mediation. J Clin Invest 71(4):916-25, 1983.

Weststrate, J.A.; Hautvast, JG. The effects of short-term carbohydrate overfeeding and prior exercise on resting metabolic rate and diet-induced thermogenesis. Metabolism 39(12):1232-9, 1990.

Weststrate, J.A.; Weys, P.J.; Poortvliet, E.J.; Deurenberg, P.; Hautvast, J.G. Diurnal variation in post-absorptive resting metabolic rate and diet-induced thermogenesis. Am J Clin Nutr 50(5):908-14, 1989.

Weststrate, J.A.; Van der Kooy, K.; Deurenberg, P.;Hautvas, J.G. The effect of psychological stress on diet-induced thermogenesis and resting metabolic rate. Eur J Clin Nutr 44(4):269-275, 1990.

Williamson, D.L.; Kirwan, J.P. A single bout of concentric resistance exercise increases basal metabolic rate 48 hours after exercise in health 59-77-year old men. J Gerontology Biol Sci Med Sci 52(6):M352-355, 1997.

Wilmore, J.H.; Stanforth, P.R.; Hudspeth, L.A.; Gagnon, J.; Daw,E.W.; Leon, A.S.; Rao, D.C.; Skinner, J.S.; Bouchard, C. Alterations in resting metabolic rate as a consequence of 20 weeks of endurance training: the HERITAGE Family Study. Am J Clin Nutrition 68(1):66-71, 1998.

Zurlo, F.; Schutz, Y.; Frascarolo, P.; Enzi, G.; Deriaz, O.; Jequier, E. Variability of resting energy expenditure in healthy volunteers during fasting and continuous enteral feeding. Crit Care Med 14(6):535-8, 1986.